

Description

SURFACE ACOUSTIC WAVE FILTER

Technical Field

5           This invention relates to a surface acoustic wave filter which is used for a communication device etc. such as a portable telephone.

Background Art

10           In recent years, along with development of mobile communication, realization of high performance and miniaturization of devices to be used have been desired. As a filter for a mobile communication device among those devices, conventionally, a surface acoustic wave filter (hereinafter, 15 called as a SAW filter) has been used widely. At the present day, as a SAW filter for an RF (Radio Frequency) stage, a longitudinal mode type and a ladder mode are mainly used. In particular, as to the ladder type SAW filter, it is possible to realize a low loss as compared with the longitudinal mode 20 SAW filter. The ladder type SAW filter is of such a configuration that a plurality of surface acoustic wave resonators (hereinafter, called as SAW resonators) are connected in a ladder mode, and configured by SAW resonators operating as a serial arm and SAW resonators operating as a parallel arm.

25           As prior art relating to the ladder type SAW filter,

JP-A-9-270663 publication discloses a method of arranging SAW resonators operating as a serial arm and SAW resonators operating as a parallel arm, with isolating them by a certain level of a distance. FIG.20 is a block diagram of a SAW filter configured in this manner and disclosed in the above-mentioned first prior art document. This SAW filter is configured by SAW resonators 902 as a serial arm, SAW resonators 903 as a parallel arm which are formed on piezoelectric substrate 901 and signal lines 904 connected to these SAW resonators 902, 903. These SAW resonators 902, 903 are arranged in such a manner that respective overlap lengths of comb-shaped electrodes configuring these SAW resonators 902, 903 overlap in a propagation direction of leaky surface acoustic wave. In this case, if it is set up in such a manner that a distance of a gap between SAW resonator 902 as the serial arm and SAW resonator 903 as the parallel arm becomes 10 times more of a wavelength of the leaky surface acoustic wave, it is possible to prevent interference of leaky surface acoustic wave of these SAW resonators 902, 903.

As another prior art relating to the ladder type SAW filter, JP-A-9-232908 publication discloses a method of arranging a slit plate between SAW resonators operating as a serial arm and SAW resonators operating as a parallel arm. FIG.21 is a block diagram of a SAW filter of the above-mentioned second prior art document, which was configured in this manner. This SAW filter is configured by SAW resonators 1002, 1005 of a serial

arm, SAW resonators 1003, 1006 of a parallel arm and slit plates 1004, 1007, which are formed on piezoelectric substrate 1001. Slit plate 1004 is disposed between SAW resonator 1002 of the serial arm and SAW resonator 1003 of the parallel arm, to block  
5 off surface acoustic waves leaking from respective SAW resonators 1002, 1003. In the same manner, slit plate 1007 is disposed between SAW resonator 1005 of the serial arm and SAW resonator 1006 of the parallel arm, to block off surface acoustic waves leaking from respective SAW resonators 1005,  
10 1006.

As another prior art relating to the ladder type SAW filter, JP-A-2000-201052 publication discloses a method of arranging in such a manner that propagation paths of surface acoustic wave in SAW resonators operating as a serial arm and SAW  
15 resonators operating as a parallel arm do not overlap. FIG.22 is a block diagram of a SAW filter of the above-mentioned third prior art document, which was configured in this manner. This SAW filter is configured by SAW resonators 1102, 1103 of a serial arm, and SAW resonator 1004 of a parallel arm, which are formed  
20 on piezoelectric substrate 1101. In this configuration, it is formed in such a manner that a surface acoustic wave propagation path of SAW resonator 1104 of the parallel arm, which is sandwiched by two SAW resonators 1102, 1103 of the serial arm, is located between surface acoustic wave propagation  
25 paths of these SAW resonators 1102, 1103 of the serial arm.

By this means, surface acoustic waves of respective SAW resonators of the serial arm and the parallel arm do not interfere with each other, and a good filter characteristic is obtained.

However, in the above-mentioned conventional disclosure  
5 examples, SAW resonators of a serial arm and SAW resonators of a parallel arm are arranged in an isolated manner by a certain level of a distance. On this account, there was such a problem that a size of a SAW filter becomes large. These SAW filters disclose a technique of eliminating an interference of surface  
10 acoustic surface waves of SAW resonators of a serial arm and SAW resonators of a parallel arm, but do not disclose a way of thinking for utilizing this at all.

The present invention aims to provide a SAW filter which is of a small size and enables a low loss, by a SAW filter with  
15 such a new configuration that a plurality of SAW resonators are arranged in proximity to each other on the same propagation path, against the above-mentioned problem.

#### Disclosure of the Invention

20 In order to accomplish the above-mentioned aimed object, a SAW filter of the present invention is comprised of a piezoelectric substrate, and at least two inter-digital transducers (hereinafter, called as IDTs) disposed in proximity to each other on the same surface acoustic wave propagation  
25 path on this piezoelectric substrate, and at least one of the

IDTs is a first IDT connected serially to a signal path and at least one is a second IDT connected between the signal path and a ground , and the first IDT and the second IDT are different in resonance frequency, and the first IDT and the second IDT are formed by such a configuration that electrode fingers of comb-shaped electrodes configuring IDT are arranged almost continuously.

According to this configuration, it is possible to obtain a SAW filter of a small size and a low loss, over having an attenuation characteristic equivalent to that of a so-called L type configuration of a ladder mode surface acoustic wave filter which is used conventionally. Such a configuration that electrode fingers are arranged almost continuously means that they are arranged in such a manner that a difference of a gap between adjacent electrode finger and electrode finger falls in an error of approximately 5% or less. By arranging in this manner, it is possible to prevent occurrence of loss due to bulk wave conversion at a boundary between IDT and IDT. Alternately, in case of arranging a strip line electrode between IDTs as described later, it is possible to prevent occurrence of loss due to bulk wave conversion at a boundary between IDT and the strip line electrode. It is also possible to utilize a second IDT from a view point of a first IDT, or the first IDT from a view point of the second IDT, as a reflector, respectively.

In the above-mentioned configuration, it is all right even if the first IDT and the second IDT are arranged in such a manner that respective surface acoustic waves are not negated with each other. In this case, it is also all right even if  
5 the first IDT and the second IDT are configured to be turned into reversed phases each other.

According to this configuration, it is possible to realize such a configuration that mutual surface acoustic waves are not denied, and therefore, it is possible to realize a SAW filter  
10 of a small size and small loss, by disposing a plurality of IDTs with different resonance frequencies in a propagation direction of surface acoustic waves.

In the above-mentioned configuration, it is all right even if it is configured in such a manner that resonance  
15 frequencies of the first IDT and the second IDT are set up to frequencies necessary for obtaining a preset filter characteristic. In that case, it is all right even if resonance frequency of the first IDT is roughly matched with anti-resonance frequency of the second IDT. By this configuration, it is  
20 possible to easily obtain a targeted filter characteristic.

In the above-mentioned configuration, it is all right even if a reflector electrode is disposed at the outermost side of IDT including the first IDT and the second IDT. According to this configuration, it is possible to effectively close  
25 surface acoustic waves in IDT, and therefore, it is possible

to realize a SAW filter by which loss is much more reduced.

In the above-mentioned configuration, it is all right even if a strip line electrode is disposed between the first IDT and the second IDT, and electrode fingers of comb-shaped electrodes which configure the first IDT and the second IDT, and electrode fingers which configure this strip line electrode are arranged almost continuously. In this case, it is also all right even if a pitch of electrode fingers of this strip line electrode is set up between a pitch of electrode fingers of the first IDT and a pitch of electrode fingers of the second IDT. According to this configuration, it is possible to effectively close over surface acoustic waves which are excited from respective IDTs in IDTs, and therefore, it is possible to reduce loss.

In the above-mentioned configuration, it is all right even if it is configured in such a manner that a pitch of plural electrode fingers, which are arranged in a boundary area of the first IDT and the second IDT, is differentiate from a pitch of electrode fingers which are arranged in respective center areas. In this case, it is also all right even if weighting method is applied to at least one of IDTs which configure a SAW filter. As this weighting method, apodized weighting, or withdrawal weighting may be applied.

According to this configuration, it is possible to easily realize a SAW filter by which an attenuation is large and loss

is small, by adjusting an attenuation and loss in tune with a design, in a necessitated frequency domain.

In the above-mentioned configuration, it is all right even if IDT is configured so as to include a dummy electrode.

5 By arranging and optimizing dummy electrodes respectively, it is possible to realize a SAW filter with much lower loss.

In the above-mentioned configuration, it is all right even if it is configured in such a manner that a third IDT, which is connected between a signal path and a ground, is arranged  
10 in proximity to each other to the first IDT, on an opposite side to such a side that the second IDT is arranged in proximity to each other. In this case, it is all right even if resonance frequency of the third IDT is differentiated from resonance frequency of the first IDT.

15 In the above-mentioned configuration, it is all right even if a fourth IDT, which is connected serially to a signal path, is arranged in proximity to each other to the second IDT, on an opposite side to such a side that the first IDT is arranged in proximity to each other. In this case, it is all right even  
20 if resonance frequency of the fourth IDT is differentiated from resonance frequency of the second IDT.

A SAW filter of the present invention is formed by such a configuration that a SAW filter with the above-mentioned configuration is used as one SAW element, and these SAW elements  
25 are connected in multiple stages. According to this



configuration, it is possible to easily obtain a SAW filter having a targeted characteristic, and it is also possible to enlarge a freedom degree of design.

According to the present invention, by arranging a plurality of SAW resonators in proximity to each other to the same propagation path, it is possible to realize a small size shape even in case of a SAW filter in which a high attenuation characteristic is demanded and a lot of resonators are required. In case that these SAW filters are connected in multiple stages as one element, it is possible to simplify a wiring pattern, and therefore, it is possible to reduce electric resistance of the wiring pattern, and it is also possible to realize a SAW filter by which loss is reduced.

#### 15 Brief Description of the Drawings

FIG.1 is a plan view showing a configuration of a SAW filter which relates to a first embodiment of the present invention.

FIG.2 is a pattern diagram for explaining a reversed phase configuration in the same embodiment.

FIG.3 is a plan view showing a SAW filter of a first modified example in the same embodiment.

FIG.4 is a plan view showing a SAW filter of a second modified example in the same embodiment.

FIG.5 is a plan view of a SAW filter which is formed by

such a configuration that a SAW filter of an one stage L type configuration, which relates to the same embodiment, is used as a basic SAW element, and these SAW elements are cascade-connected in two stages.

5           FIG.6 is a plan view explaining such a configuration that the SAW filter shown in FIG.1 is used as a basis, and a gradation area is disposed.

          FIG.7 is a view showing by enlarging a configuration of electrode fingers in a boundary area of the SAW filter shown  
10   in FIG.6.

          FIG.8 is a graph showing a result of measuring the characteristic of a SAW filter of a practical example 1.

          FIG.9 is a graph showing a result of measuring the characteristic of a SAW filter of a practical example 2.

15           FIG.10 is a graph showing a result of measuring the characteristic of a SAW filter of a practical example 3.

          FIG.11 is a graph showing a result of measuring the characteristic of a SAW filter of a comparative example 1.

          FIG.12 is a graph showing a result of measuring the  
20   characteristic of a SAW filter of a practical example 4.

          FIG.13 is a graph showing a result of measuring the characteristic of a SAW filter of a comparative example 2.

          FIG.14 is a plan view of a SAW filter of a practical example 5 which is configured in such a manner that the SAW filter shown  
25   in FIG.3 is used as a basic SAW element, and these SAW elements

are cascade-connected in four stages.

FIG.15 is a graph showing a result of measuring the characteristic as to a SAW filter of the practical example 5.

FIG.16 is a plan view showing a configuration of a SAW filter of a comparative example 3, which is produced for comparison and in which SAW resonators formed by a conventional ladder configuration are cascade-connected in multiple stages.

FIG.17 is a graph showing a result of measuring the characteristic as to the SAW filter of the comparative example 3.

FIG.18 is a plan view showing a configuration of a SAW filter which relates to a second embodiment of the present invention.

FIG.19 is a plan view showing a configuration of a SAW filter which relates to a third embodiment of the present invention.

FIG.20 is a block diagram of a conventional SAW filter disclosed in a first prior art document.

FIG.21 is a block diagram of a conventional SAW filter disclosed in a second prior art document.

FIG.22 is a block diagram of a conventional SAW filter disclosed in a third prior art document.

#### Best Mode for Carrying Out the Invention

Hereinafter, embodiments of the present invention will

be explained in detail by use of drawings. Since the same reference numerals and signs are given to the same elements, there is such a case that explanations will be omitted. Drawings shown below are pattern views, and the number of electrode  
5 fingers and a pitch are not described accurately.

(First Embodiment)

FIG.1 is a plan view showing a configuration of a SAW filter which relates to a first embodiment. In general, a SAW filter is packaged by ceramic, resin etc., and used, but FIG.1  
10 shows only a configuration on a piezoelectric substrate 201. As shown in FIG.1, in case of a SAW filter of this embodiment, it is composed by such a configuration that first IDT 202 and second IDT 203 are arranged on a surface of piezoelectric substrate 201 which is formed by lithium tantalate ( $\text{LiTaO}_3$ )  
15 of  $39^\circ$  Y-cut X propagation in such a manner that they are on the same propagation path, reflector electrodes 207 are disposed on respective end portions.

First IDT 202 is arranged between one terminal 204 and the other terminal 205 of input/output terminals, i.e., serially  
20 to a signal path, and can carry out an operation which is equivalent to that of SAW resonators of a serial arm. Second IDT 203 is arranged in parallel to the signal path from a portion between one terminal 204 of the input/output terminals and first IDT 202. This second IDT 203 is connected to one terminal 204  
25 and the first IDT by wiring electrode 206. By the suchlike

arrangement and connection configuration, second IDT 203 can carry out an operation which is equivalent to that of SAW resonators of a parallel arm.

As to first IDT 202 and second IDT 203, electrode fingers of comb-shaped electrode, which configure respective IDTs, are arranged almost continuously, on the same propagation path of surface acoustic waves which are excited by respective SAW resonators. At this time, first IDT 202 and second IDT 203 are configured in such a manner that surface acoustic waves, which are excited by respective SAW resonators, are not negated with each other. Reflector electrodes 207 are arranged on an opposite side to an adjacent side of first IDT 202 and second IDT 203. The SAW filter of first embodiment is formed by adopting the suchlike configuration.

Wiring electrode 206 and one terminal 204 and other terminal 205 of the comb-shaped electrode which configures first IDT 202 and other terminal 205 are respectively connected by a wire lead etc. The other of the comb-shaped electrode, which configures second IDT 203, is connected to an earth terminal by a wire lead etc. in the same manner, and is grounded.

An electrode finger pitch of the comb-shaped electrode which configures first IDT 202 is smaller than an electrode finger pitch of the comb-shaped electrode which configures second IDT 203, and respective pitches are set up so as to realize a filter characteristic based on a design value. An electrode

finger pitch of reflector electrode 207 is set up so as to become an intermediate value between an electrode finger pitch of first IDT 202 and an electrode finger pitch of second IDT 203.

By arranging first IDT 202 and second IDT 203 in proximity  
5 to each other to close over them on one propagation path, as to respective SAW resonators, it becomes equivalent to such a matter that its resonator length is lengthened in substance, and it is possible to improve a SAW resonator characteristic. In consequence, as a SAW filter, it is possible to obtain a  
10 band-pass type and small loss characteristic. By such a matter that it is possible to arrange first IDT 202 and second IDT 203 in proximity to each other and to shorten a wiring electrode, miniaturization of a SAW filter can be realized. The above-described configuration also becomes a basic  
15 configuration unit of an L type SAW filter.

As described above, a SAW filter of the present invention can realize a small size and small loss filter characteristic, by arranging a plurality of SAW resonators in proximity to each other on the same propagation path.

20 As a method of changing resonance frequencies of first IDT 202 and second IDT 203, there are a method of changing a width of electrode fingers, a method of changing a pitch of electrode fingers, and so on. However, judging from a view point of such a matter that it is possible to enlarge a design  
25 freedom degree of a SAW filter and of easiness of a process,

the method of changing an electrode finger pitch is desirable.

Generally speaking, in case of configuring SAW resonators, respective pitches are determined in such a manner that peak frequency of an IDT characteristic is matched with center  
5 frequency of a reflection characteristic of a reflector electrode. However, since the reflection characteristic is flat in a relatively wide frequency area, a resonance characteristic is obtained if it is in this flat area, without being accompanied with large deterioration of a characteristic.  
10 Therefore, it is all right if a reflection characteristic falls in a flat area in peak frequency of all IDT characteristics, and it is desirable to make a pitch of reflector electrodes larger than a pitch of IDTs having a minimum pitch, and smaller than a pitch of IDTs having a maximum pitch. By arranging IDTs  
15 in such a manner that respective surface acoustic waves are not negated, it is possible to avoid mutual interference.

In case of arranging first IDT 202 and second IDT 203 in such a manner that surface acoustic waves are not negated, it is desirable to configure in such a manner that first IDT  
20 202 and second IDT 203 to be turned into reversed phases each other.

The reversed phase in the present invention means a configuration as shown in FIG.2. FIG.2 is a pattern diagram for explaining the reversed phase, and shows it by enlarging  
25 a boundary area portion of first IDT 22 and second IDT 23. In

this figure, strip line electrode 31 is disposed between first IDT 22 and second IDT 23. Surface acoustic wave 25, which is excited from first IDT 22 and second IDT 23, is also shown schematically. In case of the suchlike configuration, as shown  
5 in the figure, peaks and troughs of surface acoustic wave 25 are formed by electrode finger 221 which is the closest to second IDT 23, in first IDT 22, and electrode finger 231 which is the closest to first IDT 22, in second IDT 23, and one comb-shaped electrodes, which configure first IDT 22 and second IDT 23,  
10 are connected in common. The reversed phase in the present invention means the suchlike arrangement configuration. In order to realizing the suchlike reversed phase, strip line electrode 31 shown in the figure is not indispensable, and the reversed phase configuration is possible without disposing  
15 strip line electrode 31.

In the SAW filter of this embodiment, reflector electrode 207 is arranged, but the present invention is not limited to this. That is, in case of such a configuration that containment of surface acoustic waves can be realized more sufficiently  
20 than in another method, it is all right even if reflector electrode 207 is not particularly disposed.

FIG.3 is a plan view showing a SAW filter of a first modified example in this embodiment. Also in the SAW filter of this modified example, only a configuration on piezoelectric  
25 substrate 201 is shown in the same manner as in FIG.1. This



SAW filter of the first modified example is characterized in that roughly several pieces of strip line electrodes 301 are arranged between first IDT 202 and second IDT 203. It is preferable that its electrode finger pitch is set up so as to become an intermediate value between an electrode finger pitch of first IDT 202 and an electrode finger pitch of second IDT 203. A pitch of electrode fingers of strip line electrode 301 is set up so as to become the above-mentioned intermediate value, but there is no need to make all pitches of electrode fingers constant, and it is all right even if it is changed in a stepwise fashion and it is also all right even if it is made as gradation in which it is changed continuously. This strip line electrode 301 is operated as a reflector electrode.

FIG.4 is a plan view showing a SAW filter of a second modified example in this embodiment. Also in the SAW filter of this modified example, only a configuration on piezoelectric substrate 201 is shown in the same manner as in FIG.1. This SAW filter of the second modified example is characterized in that dummy electrodes 401, 402 shown in the figure are disposed on first IDT 404 and second IDT 405, respectively, and others are the same as the SAW filter configuration shown in FIG.1. By arranging these dummy electrodes 401, 402 respectively to carry out optimization, it is possible to realize a SAW filter with much lower loss.

In the above-described embodiment, a one stage, L type

configuration SAW filter was explained, but the present invention is not limited to this. For example, it is all right even if a multiple stage configuration SAW filter shown in FIG.5 is realized.

5           FIG.5 is a plan view of a SAW filter which is formed by such a configuration that the one stage, L type configuration SAW filter shown in FIG.1 is used as a basic SAW element and these SAW elements are cascade-connected in two stages. First SAW element 501 is formed by such a configuration that first  
10 IDT 2021 and second IDT 2031 are arranged on a surface of piezoelectric substrate 201 so as to be located on the same propagation path, and reflector electrodes 2071 are disposed on respective end portions. Second SAW element 502 is formed by such a configuration that first IDT 2022 and second IDT 2032  
15 are arranged on a surface of piezoelectric substrate 201 so as to be located on the same propagation path and reflector electrodes 2072 are disposed on respective end portions, in the same manner.

          One of comb-shaped electrodes which configure first IDT  
20 2021 is connected to one terminal 204 of input/output terminals, and the other of the comb-shaped electrodes is connected to wiring electrode 206. One of comb-shaped electrodes which configure second IDT 2031 is connected to earth, and the other is connected to wiring electrode 206.

25           One of comb-shaped electrodes which configure first IDT

2022 is connected to one terminal 205 of input/output terminals,  
and the other of the comb-shaped electrodes is connected to  
wiring electrode 206. One of comb-shaped electrodes which  
configure second IDT 2032 is connected to earth, and the other  
5 is connected to wiring electrode 206.

By adopting the suchlike configuration, a pattern shape  
including IDTs and reflector electrodes formed on piezoelectric  
substrate 201 becomes almost a rectangular shape as a whole.  
Therefore, a space factor of a pattern on a chip is improved.  
10 In consequence, miniaturization of a chip as a SAW filter becomes  
possible. Connection between first SAW element 501 and second  
SAW element 502 is realized only by wiring electrode 206, and  
since a very simple configuration is realized, realization of  
a low loss can be carried out.

15 Hereinafter, a concrete configuration of a SAW filter  
which relates to this embodiment and a result of its  
characteristic which was obtained by simulation will be  
explained.

FIG.6 is a plan view explaining such a configuration that  
20 the SAW filter shown in FIG.1 is used as a basis and a gradation  
area is disposed. This SAW filter is formed by such a  
configuration that first IDT 202 and second IDT 203 have  
different resonance frequencies, and as to first IDT 202 and  
second IDT 203, electrode fingers of comb-shaped electrodes  
25 which configure IDTs are arranged almost continuously in such

a manner that respective surface acoustic waves are not negated. Hereinafter, this SAW filter is called as a SAW filter of a practical example 1.

Concretely speaking, this SAW filter of the practical example 1 is characterized by such a configuration that a pitch of plural electrode fingers of gradation areas 2026, 2036, which are boundary areas of first IDT 202 and second IDT 203, is differentiated from a pitch of electrode fingers of equal pitch areas 2025, 2035 at respective center areas, i.e., gradation is disposed. FIG.7 is a view showing by enlarging a configuration of electrode fingers in this boundary area. FIG.7 is a schematic view, and does not express the number of electrode fingers etc. accurately. TABLE 1 shows the number of electrode fingers and pitches of this SAW filter.

As understood from TABLE 1 and FIG.7, 215 pieces of electrode fingers are disposed in equal pitch area 2025 of first IDT 202, and a pitch in this area is  $2.341\mu\text{m}$ . Gradation area 2026 is disposed in a region from an end portion of this equal pitch area 2025 up to a boundary portion of second IDT 203. The number of electrode fingers in gradation area 2026 is 10 pieces, and its pitch is changed continuously from  $2.341\mu\text{m}$  as a pitch of end portions in the equal pitch area up to  $2.411\mu\text{m}$  as a pitch of the boundary portion of second IDT 203.

Gradation area 2036 of second IDT 203 is changed continuously from  $2.411\mu\text{m}$  as a pitch of end portions in gradation

area 2026 of first IDT 202 up to  $2.429\mu\text{m}$  as a pitch of equal pitch area 2035. The number of electrode fingers in this gradation area 2036 is 10 pieces, and the number of electrode fingers in equal pitch area 2035 is 135 pieces.

5           The number of electrode fingers of reflector electrode 207 which is adjacent to first IDT 202 is 35 pieces, and its pitch is set to  $2.404\mu\text{m}$ . The number of electrode fingers of reflector electrode 207 which is adjacent to second IDT 203 is 35 pieces, and its pitch is set to  $2.418\mu\text{m}$ . Piezoelectric  
10 substrate 201 is formed by lithium tantalate ( $\text{LiTaO}_3$ ) of  $39^\circ$  Y-cut X propagation, and an electrode film thickness is set to approximately  $0.4\mu\text{m}$ . A characteristic of the SAW filter of the practical example 1 which is formed by the above-mentioned configuration is obtained, and its result is shown in FIG.8.  
15 As understood from FIG.8, in the SAW filter of the practical example 1, losses at 824MHz and 849MHz were 0.65dB, 0.28dB.

TABLE 1

		Number of Electrode Fingers (piece)	Pitch ( $\mu\text{m}$ )
Reflector Electrode 207		35	2.404
First IDT 202	Equal Pitch Area 2025	215	2.341
	Gradation Area 2026	10	2.411 (right end portion of first IDT 202)
Second IDT 203	Gradation Area 2036	10	2.411 (left end portion of second IDT 203)
	Equal Pitch Area 2035	135	2.429
Reflector Electrode 207		35	2.418

\* An overlap length is  $115\mu\text{m}$ , and  $\eta$  is 0.52, and made constant.

Next, in the same manner as the SAW filter of the practical example 1, manufactured was such a SAW filter that thinned-out apodization was added further to such a configuration that a gradation area is disposed. This is called as a SAW filter of a practical example 2. The SAW filter of the practical example 2 is the same as the SAW filter of the practical example 1 as to its configuration, but the number of electrode fingers and a pitch are different.

TABLE 2 shows the number of electrode fingers and pitches of the SAW filter of the practical example 2. As to things other than a configuration shown in TABLE 2, they are the same as those of the SAW filter of the practical example 1, and therefore, explanations will be omitted.

A characteristic of the SAW filter of the practical example 2, which is formed by the above-mentioned configuration, is obtained, and its result is shown in FIG. 9. As understood from FIG. 9, in the SAW filter of the practical example 2, losses at 824MHz and 849MHz were 0.52dB, 0.29dB.

TABLE 2

		Number of Electrode Fingers (piece)	Pitch ( $\mu\text{m}$ )
Reflector Electrode 207		35	2.383
First IDT 202	Equal Pitch Area 2025	215	2.321
	Gradation Area 2026	10	2.390 (right end portion of first IDT 202)
Second IDT 203	Gradation Area 2036	10	2.390 (left end portion of second IDT 203)
	Equal Pitch Area 2035	135	2.408
Reflector Electrode 207		35	2.397

\* An overlap length is  $115\mu\text{m}$ , and  $\eta$  is 0.52, and made constant.

In the same manner as the SAW filter of the practical example 1, manufactured was such a SAW filter that weighting method was added further to such a configuration that a gradation area is disposed. This is called as a SAW filter of a practical example 3. As to the weighting method, its optimum value was set up over evaluating a characteristic by simulation. A characteristic of the SAW filter of the practical example 3 which was manufactured in this manner was obtained, and its result is shown in FIG.10. As understood from FIG.10, in the SAW filter of the practical example 3, losses at 824MHz and 849MHz were 0.56dB, 0.28dB.

In order to compare with a SAW filter of the present invention, manufactured was a SAW filter which is formed by a conventional ladder mode configuration. This is called as a SAW filter of a comparative example 1. A characteristic of the SAW filter of this comparative example 1 was measured, and its result is shown in FIG.11. As understood from FIG.11, in the SAW filter of the comparative example 1, losses at 824MHz and 849MHz were 0.65dB, 0.28dB.

These characteristics are shown collectively in TABLE 3. As understood from TABLE 3, it could be confirmed that the SAW filters of the practical example 2 and the practical example 3 can obtain more favorable characteristic than that of the

SAW filter of the comparative example 1, except for the SAW filter of the practical example 1. In case of the SAW filter of the practical example 1, its characteristic was the same as that of the SAW filter of the comparative example 1, but it is characterized on such a point that it is possible to miniaturize it much more than the SAW filter of the comparative example 1.

TABLE 3.

	SAW filter of Practical Example 1	SAW filter of Practical Example 2	SAW filter of Practical Example 3	SAW filter of Comparative Example 1
824MHz	0.65dB	0.52dB	0.56dB	0.65dB
894MHz	0.28dB	0.29dB	0.28dB	0.28dB

Next, manufactured was a SAW filter which was configured in such a manner that a strip line electrode is disposed between a first IDT and a second IDT, and electrode fingers of comb-shaped electrodes which configure the first IDT and the second IDT, and electrode fingers which configure the strip line electrode or a reflector electrode are arranged so as to become almost continuously. This is based on the SAW filter shown in FIG.3, and the number of electrode fingers and pitches of the manufactured SAW filter are shown in TABLE 4. This is called as a SAW filter of a practical example 4.

A characteristic of the SAW filter of the practical example 4 manufactured based on TABLE 4 was obtained, and its result



is shown in FIG.12. As understood from FIG.12, in the SAW filter of the practical example 4, losses at 824MHz and 849MHz were 0.70dB, 0.25dB.

5                      TABLE 4

	Number of Electrode Fingers (piece)	Pitch ( $\mu\text{m}$ )
Reflector Electrode 207	35	2.404
First IDT 202	225	2.341
Strip Line Electrode 301	35	2.411
Second IDT 203	145	2.429
Reflector Electrode 207	35	2.418

In order to compare with the SAW filter of the practical example 4, also manufactured was a SAW filter of a conventional ladder mode configuration. This is called as a SAW filter of a comparative example 2. A characteristic of the SAW filter of this comparative example 2 was measured, and its result is shown in FIG.13. As understood from FIG.13, in the SAW filter of the comparative example 2, losses at 824MHz and 849MHz were 0.70dB, 0.25dB.

15                      In case of the SAW filter of the practical example 4, a characteristic itself was of the same result as that of a conventional ladder mode configuration, but it is characterized on such a point that miniaturization is possible.

Next, manufactured was a SAW filter in which the SAW filter shown in FIG.3 is used as a basic SAW element and these things

are cascade-connected in multiple stages, and its characteristic was obtained, and its result will be described.

FIG.14 is a plan view of a SAW filter which is configured in such a manner that the SAW filter shown in FIG.3 is used as a basic SAW element and these SAW elements are cascade-connected in 4 stages. This is called as a SAW filter of a practical example 5. Piezoelectric substrate 201 is formed by use of lithium tantalate ( $\text{LiTaO}_3$ ) of  $39^\circ$  Y-cut X propagation, and an electrode film thickness is set to approximately  $0.4\mu\text{m}$ . The number of electrode fingers and pitches of respective IDTs and reflector electrodes from a first stage up to a fourth stage are shown in TABLE 5.

A first stage of this SAW filter of the practical example 5 is configured by first IDT 502, second IDT 503, reflector electrodes 504, 505 on both sides, and strip line electrode 506 at a center portion. A second stage is configured by first IDT 512, second IDT 513, reflector electrodes 514, 515 on both sides, and strip line electrode 516 at a center portion. A third stage is configured by first IDT 522, second IDT 523, reflector electrodes 524, 525 on both sides, and strip line electrode 526 at a center portion. A final fourth stage is configured by first IDT 532, and reflector electrodes 534, 535 which are arranged on both sides thereof.

TABLE 5

	First Stage				
	Reflector Electrode 504	First IDT 502	Strip Line Electrode 506	Second IDT 503	Reflector Electrode 505
Overlap lengths ( $\mu\text{m}$ )	---	115	---	115	---
Number of Electrode Fingers (piece)	35	225	23	145	35
Electrode Finger Pitch ( $\mu\text{m}$ )	2.404	2.341	2.411	2.429	2.418
	Second Stage				
	Reflector Electrode 514	First IDT 512	Strip Line Electrode 516	Second IDT 513	Reflector Electrode 515
Overlap lengths ( $\mu\text{m}$ )	---	55	---	55	---
Number of Electrode Fingers (piece)	35	157	23	181	35
Electrode Finger Pitch ( $\mu\text{m}$ )	2.404	2.334	2.411	2.427	2.418
	Third Stage				
	Reflector Electrode 524	First IDT 522	Strip Line Electrode 526	Second IDT 523	Reflector Electrode 525
Overlap lengths ( $\mu\text{m}$ )	---	75	---	75	---
Number of Electrode Fingers (piece)	35	201	23	153	35
Electrode Finger Pitch ( $\mu\text{m}$ )	2.415	2.434	2.406	2.309	2.392
	Fourth Stage				
	Reflector Electrode 534	First IDT 532	Reflector Electrode 535		
Overlap lengths ( $\mu\text{m}$ )	---	40	---		
Number of Electrode Fingers (piece)	35	235	35		
Electrode Finger Pitch ( $\mu\text{m}$ )	2.411	2.334	2.411		

These IDTs are connected by wiring electrodes 540, 541, 542.

One of comb-shaped electrodes, which configure first IDT 502 at a first stage, is connected to one terminal 204 of input/output terminals, and the other of the comb-shaped electrodes, which configure first IDT 532 at a fourth stage, is connected to other terminal 205 of input/output terminals. Strip line electrodes 506, 516, 526 are operated as reflector electrodes, respectively.

FIG.15 is a graph showing a result of measuring the characteristic as to a SAW filter of the practical example 5 with the suchlike configuration. AS understood from FIG.15, in the SAW filter of the practical example 5, losses at 824MHz and 849MHz were 0.92dB, 1.29dB.

In order to compare with this SAW filter, manufactured was a SAW filter of such a configuration that SAW resonators, which are formed by a conventional ladder mode configuration, are cascade-connected in multiple stages. FIG.16 is a plan view showing a configuration of this SAW filter. This SAW filter is configured by SAW resonators 600 of a serial arm formed on piezoelectric substrate 650, SAW resonators 610 of a parallel arm, and signal line 640 connected to these SAW resonators 600, 610. SAW resonators 600 of a serial arm are connected to one terminal 620 and other terminal 630 of input/output terminals, respectively. The number of electrode fingers, a pitch, a

overlap lengths etc. are set up to be matched with a pass band of the SAW filter of the practical example 5.

A SAW filter of the suchlike configuration is hereinafter called as a SAW filter of a comparative example 3. FIG.17 is  
5 a graph showing a result of measuring the characteristic as to a SAW filter of this comparative example 3. As understood from FIG.17, in the SAW filter of the comparative example 3, losses at 824MHz and 849MHz were 0.93dB, 1.29dB.

Judging from these results, the SAW filter of the practical  
10 example 5 is characterized on such a point that it can be miniaturized as a whole, although an improvement level is small as compared with the SAW filter of the comparative example 3.

In the SAW filter shown in the above-described practical example, gradation is formed in such a manner that a pitch is  
15 changed continuously, but the present invention is not limited to this. For example, a pitch may be changed in a stepwise fashion. In the SAW filter shown in the above-described practical example in the same manner, shown was such a configuration that weighting method was applied to IDT, but  
20 there is no limitation to the suchlike configuration and withdrawal weighting method may be applied.

Although it is not explicitly explained, in the first embodiment and the SAW filters of the practical examples manufactured based upon it, that resonance frequencies of the  
25 first IDT and the second IDT are set up to frequencies necessary

for obtaining a preset filter characteristic, but it is figured out from TABLE 1 through TABLE 5 and their explanations, as a matter of course. It is possible to obtain a favorable characteristic in the same manner, even if resonant frequency of the first IDT is nearly matched with anti-resonance frequency of the second IDT.

In the present invention, it is all right even if it is configured in such a manner that a third IDT, which is connected between a signal path and a ground, is arranged, on an opposite side to such a side that a second IDT is arranged to a first IDT in such a manner that electrode fingers of its comb-shaped electrode are located continuously, in such a manner that electrode fingers of its comb-shaped electrode are located continuously to electrode fingers of the comb-shaped electrode of the first IDT. Alternately, it is also all right even if it is configured in such a manner that a fourth IDT, which is connected serially to a signal path, is arranged, on an opposite side to such a side that a first IDT is arranged to a second IDT in such a manner that electrode fingers of its comb-shaped electrode are located continuously, in such a manner that electrode fingers of its comb-shaped electrode are located continuously to electrode fingers of the comb-shaped electrode of the second IDT. By adopting these configurations, it is possible to realize a SAW filter which is of a small size and a low loss, in the same manner.

(Second Embodiment)

FIG.18 is a plan view showing a configuration of a SAW filter which relates to a second embodiment of the present invention. A different point between the SAW filter of this embodiment and the SAW filter of the first embodiment is such a point that an L type configuration was mainly used in the first embodiment, whereas in this embodiment, a  $\pi$  type configuration is mainly used.

The SAW filter of this embodiment is configured by first IDT 702, second IDT 703, third IDT 704 on piezoelectric substrate 701, and reflector electrodes 709 arranged on both ends.

First IDT 702 is arranged between one terminal 705 of input/output terminals and other terminal 706 of the input/output terminals, i.e., serially to a signal path. By this arrangement, this first IDT 702 can carry out an operation which is equivalent to that of SAW resonators of a serial arm. Second IDT 703 is arranged in parallel to a signal path from a portion between one terminal 705 of input/output terminals and first IDT 702, and connected to first IDT 702 and one terminal 705 by wiring electrode 707. By this arrangement, second IDT 703 can carry out an operation which is equivalent to that of SAW resonators of a parallel arm.

Third IDT 704 is arranged in parallel to a signal path from a portion between other terminal 706 of input/output terminals and first IDT 702, and connected to first IDT 702

and other terminal 706 by wiring electrode 708. By this arrangement, third IDT 704 can carry out an operation which is equivalent to that of SAW resonators of a parallel arm.

First IDT 702, second IDT 703 and third IDT 704 are arranged  
5 in proximity to one another, on the same propagation path of surface acoustic waves which are excited by respective SAW resonators. It is configured in such a manner that, at this time, surface acoustic waves, which are excited by respective SAW resonators, are not negated each other. On this account,  
10 it is desirable to make them in reversed phases. Reflector electrodes 709 are arranged on respective one end sides of second IDT 703 and third IDT 704, respectively, as shown in the figure. The SAW filter of this embodiment is formed by the above-mentioned configuration.

15 Electrode finger pitches are set up in such a manner that an electrode finger pitch of first IDT 702 is smaller than electrode finger pitches of second IDT 703 and third IDT 704 and a filter characteristic based on a design value can be obtained. An electrode finger pitch of reflector electrode  
20 709 is set up so as to become an intermediate value of an electrode finger pitch of first IDT 702, and electrode finger pitches of second IDT 703 and third IDT 704.

By adopting the above-mentioned configuration, first IDT 702, second IDT 703 and third IDT 704 in the SAW filter of this  
25 embodiment are arranged in proximity to one another, and surface



acoustic waves are closed over on the same propagation path. Therefore, respective SAW resonators become equivalent to such a matter that a resonator length is lengthened in substance. In consequence, it is possible to improve a characteristic of SAW resonators, and therefore, it is possible to obtain a band pass type and small loss characteristic, as a SAW filter.

By such a matter that first IDT 702, second IDT 703 and third IDT 704 are arranged in proximity to one another and a wiring electrode line length for connecting can be reduced, it is possible to realize miniaturization as a SAW filter. As to the suchlike SAW filter, a  $\pi$  type configuration is a basic configuration unit.

As explained above, the SAW filter of this embodiment can realize a small size and small loss characteristic, by arranging a plurality of SAW resonators in proximity to one another on the same propagation path.

In this embodiment, a reflector electrode was arranged, but it is all right even if the reflector electrode is not disposed by use of such a configuration that it is possible to close over surface acoustic waves in IDTs sufficiently. It is also all right even if it is configured in such a manner that roughly several pieces of reflector electrodes or strip line electrodes are disposed between first IDT 702, second IDT 703 and third IDT 704. It is preferable to set up an electrode finger pitch of these reflector electrodes or strip line electrodes to an

intermediate value of an electrode finger pitch of first IDT 702, and electrode finger pitches of second IDT 703 and third IDT 704.

It is all right even if dummy electrodes are arranged  
5 on first IDT 702, second IDT 703 and third IDT 704, respectively.  
By optimizing this arrangement configuration of dummy electrodes, it is possible to reduce a loss much more.

Even in this embodiment, it is possible to realize a small size SAW filter, over improving a filter characteristic, by  
10 disposing a gradation area as explained in the first embodiment and realizing an apodized weighting method or thinned-out electrode configuration etc.

#### (Third Embodiment)

FIG.19 is a plan view showing a configuration of a SAW  
15 filter which relates to a third embodiment of the present invention. A different point between the SAW filter of this embodiment and the SAW filter of the first embodiment is that an L type configuration is used in the first embodiment, and a T type configuration is used in this embodiment. As shown  
20 in FIG.19, the SAW filter of this embodiment is configured by first IDT 802, second IDT 803, fourth IDT 804 on piezoelectric substrate 801 and reflector electrodes 808 arranged on both end portions.

First IDT 802 and fourth IDT 804 are arranged between  
25 one terminal 805 of input/output terminals and other terminal

806 of the input/output terminals, i.e. serially to a signal path. By this configuration, these things can carry out an operation which is equivalent to that of SAW resonators of a serial arm.

5           Second IDT 803 is arranged in parallel to a signal path from a portion between first IDT 802 and fourth IDT 804. This second IDT 803 is connected to one of comb-shaped electrodes which configure first IDT 802 and fourth IDT 804, respectively, by wiring electrode 807. By this configuration, second IDT  
10   803 can carry out an operation which is equivalent to that of SAW resonators of a parallel arm.

          First IDT 802, second IDT 803 and fourth IDT 804 are arranged in proximity to one another on the same propagation path of surface acoustic waves which are excited by respective  
15   resonators. It is configured in such a manner that, at this time, surface acoustic waves, which are excited by respective SAW resonators, are not negated each other. On this account, it is desirable to make them in reversed phases. Reflector electrodes 808 are arranged on an opposite side to adjacent  
20   sides of first IDT 802, second IDT 803 and fourth IDT 804.

          Electrode finger pitches are set up in such a manner that electrode finger pitches of first IDT 802 and fourth IDT 804 are smaller than an electrode finger pitch of second IDT 803 and a filter characteristic based on a design value can be  
25   obtained. An electrode finger pitch of reflector electrode

808 is set up so as to become an intermediate value of electrode finger pitches of first IDT 802 and fourth IDT 804, and an electrode finger pitch of second IDT 803.

By adopting the above-mentioned configuration, first IDT  
5 802, second IDT 803 and fourth IDT 804 in the SAW filter of this embodiment are arranged in proximity to one another, and surface acoustic waves are closed over on the same propagation path, and therefore, respective SAW resonators become equivalent to such a matter that a resonator length is lengthened  
10 in substance. In consequence, it is possible to realize a SAW filter which improves a characteristic of SAW resonators and which has a band pass type and small loss characteristic. By such a matter that first IDT 802, second IDT 803 and fourth IDT 804 are arranged in proximity to one another and a wiring  
15 electrode line length for connection can be reduced, it is possible to realize miniaturization of a SAW filter. As to the suchlike SAW filter in this case, a T type configuration is a basic configuration unit.

As explained above, a SAW filter of the present invention  
20 can realize a small size and small loss characteristic, by arranging a plurality of SAW resonators in proximity to one another on the same propagation path.

Even in this embodiment, it is possible to realize a small size SAW filter over improving a filter characteristic, by  
25 disposing a gradation area and adopting an apodization or

thinned-out electrode configuration etc. as explained in the first embodiment. In this embodiment, reflector electrode are arranged, but it is all right even if reflector electrodes are not disposed in particular, by use of such a configuration that  
5 it is possible to close over surface acoustic waves in IDTs sufficiently.

It is also all right even if roughly several pieces of stripline electrodes are disposed between first IDT 802, second IDT 803 and fourth IDT 804. It is preferable to set up an  
10 electrode finger pitch of these strip line electrodes to an intermediate value of an electrode finger pitch of second IDT 803 and electrode finger pitches of first IDT 802 and fourth IDT 804.

It is all right even if dummy electrodes are arranged  
15 on first IDT 802, second IDT 803 and fourth IDT 804, respectively. By optimizing dummy electrodes based upon a design value, it is possible to reduce a loss much more.

In this embodiment, three IDTs are arranged on the same propagation path, but it is all right even if they are four  
20 or more. Also with regard to connection and arrangement, it is all right even if a plurality of IDTs are arranged in proximity to one another.

In this embodiment, a SAW filter of one stage configuration was explained, but it is all right even if this one stage  
25 configuration SAW filter is used as a basic SAW element and

they are cascade-connected in multiple stages to realize a SAW filter of a multiple stage configuration. It is also all right even if it is not limited to a T type configuration, but it is combined with an L type configuration, a  $\pi$  type configuration  
5 or another configuration such as one terminal pair surface acoustic wave resonator element.

#### Industrial Applicability

A SAW filter, which relates to the present invention,  
10 is a filter with a high attenuation characteristic requiring a lot of SAW resonators, and has such an advantage that it is possible to reduce a chip size and reduce an insertion loss at the same time, and useful for a filter in a communication field such as portable telephones or in a video field such as  
15 televisions, and so on.